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Technology progress on The Hyperspectral Microwave Photonic Instrument (HyMPI)

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Introduction

- **Microwave (MW) sounders like AMSU and ATMS represent the primary source of information for Numerical Weather Prediction for their capability to sound atmospheric temperature and water vapor under all-sky conditions.**

- **Dr. Antonia Gambacorta, presentation for the scientific details:**

  Session: "Informing Next Generation Space Architectures through Innovation and Partnerships"
  Title: "Informing Next Generation Hyperspectral Microwave Sensors: Introducing the Hyperspectral Microwave Photonic Instrument (HyMPI)"
  Date / time / location: January 31 / 11.15 – 11.30 / 309

- **This presentation describes our effort at NASA's GSFC to overcome limits of RF technology and propose a new technology concept to overcome stalled progress in MW technology.**

- **This is photonic integrated circuits applied to MW Earth Remote Sensing.**

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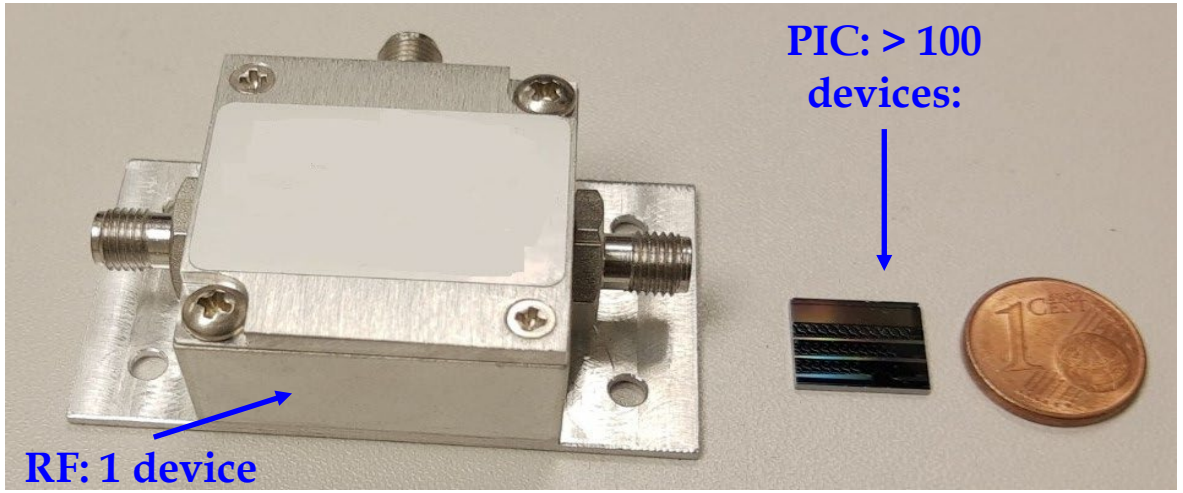
Integrated photonics

- **Integrated photonics: emerging branch of photonics in which waveguides and devices are fabricated as an integrated structure onto the surface of a flat substrate**
  - **The carrier of the signals are photons (not electrons)**

- **Properties of photonic integrated circuits (PIC):**
  - **Ultra compact devices (low size/weight)**
  - **Low power consumption**
  - **Process ultra-high bandwidth**
  - **Tunable channels**
  - **Reduced cost with integration**
  - **CMOS compatible**

RF vs PIC dimensions:



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What PIC can do?

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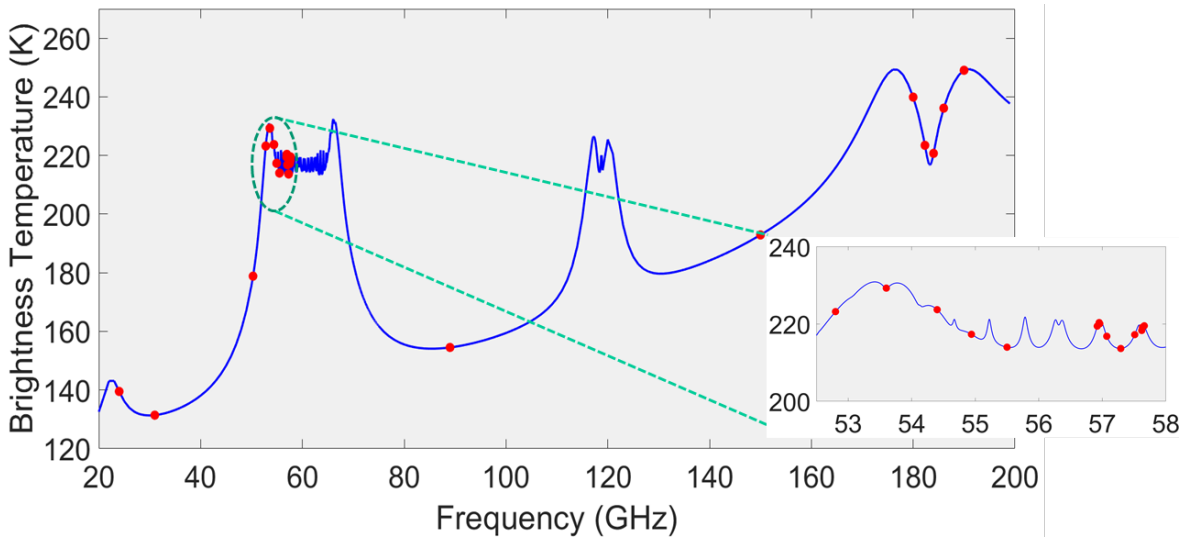

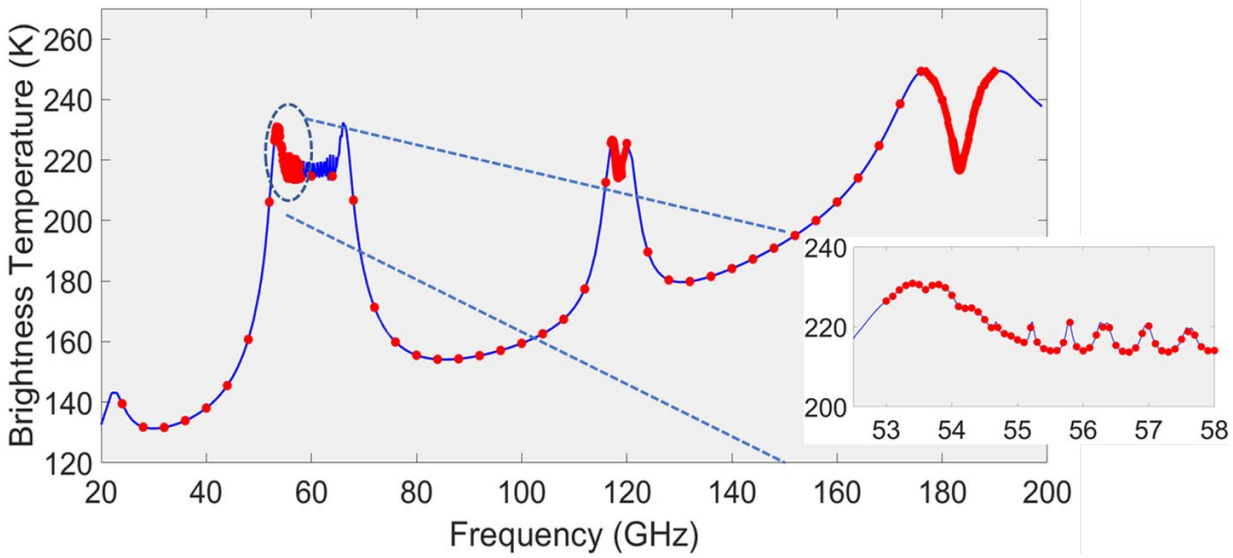

- **ATMS:**
  - **~20 non-contiguous channels**
  - **Missing critical information**
  - **High footprint and power consumption**

- **PIC enabled hyperspectral MW technology:**
  - **Contiguous spectral coverage**
  - **Hyperspectral resolution: 10 MHz (or lower!) with support of Application Specific Integrated Circuits**
  - **Cubesat volume**

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The HyMPI concept

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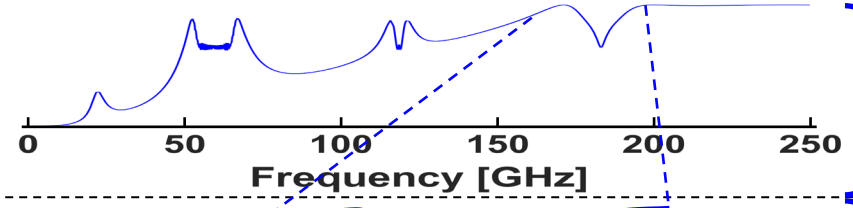
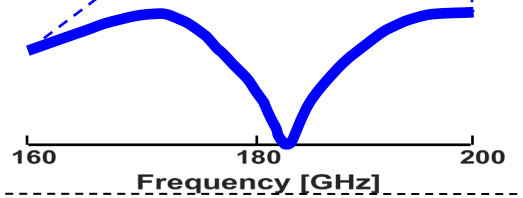
Antenna Captures MW spectrum.



RF domain

G-Band Rx Amplifies spectra.

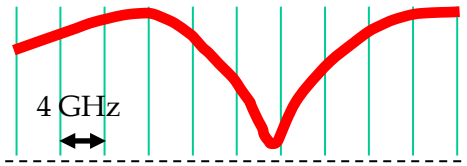


RF domain

EOM Converts microwave spectrum to optical domain.

Optical domain

SAWG Separates spectrum into 10 x 4 GHz sub-bands.



Optical domain

BPR Sub-bands with structure are mixed with a new optical tone and digitized (Hi-Res Channels).

ASIC

PD Sub-bands with minimal structure are measured directly (Lo-Res Channel).

Baseband domain (0 – 4 GHz)

- **HyMPI is based on PICs developed in different platforms (III-V, silicon nitride, …)**
- **HyMPI enables a modular approach:**
  - **The single HyMPI system focuses on 40 GHz portion of the MW spectrum**
  - **The PICs allows to use the parallel systems to cover 250 GHz MW spectrum**
- **HyMPI's goal:**
  - **Provide broadband spectral coverage.**
  - **Hyperspectral (thousands of channels, up to 500 kHz resolution) instrument.**
  - **Limited SWaP-C for PBL sensing**

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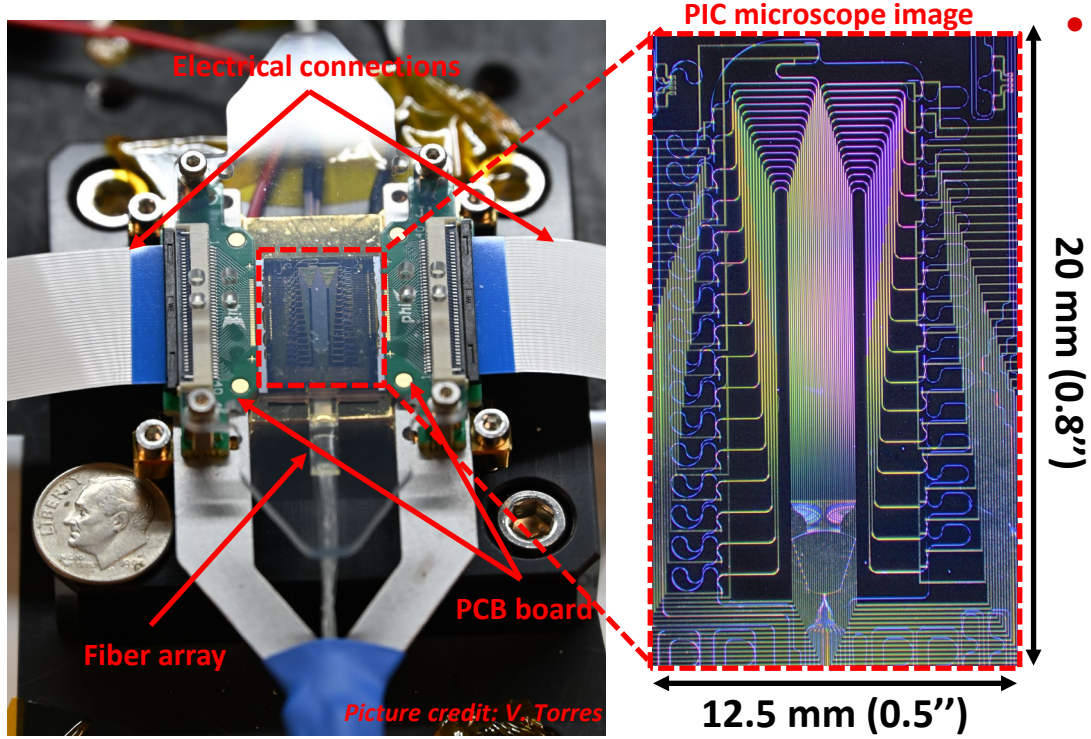
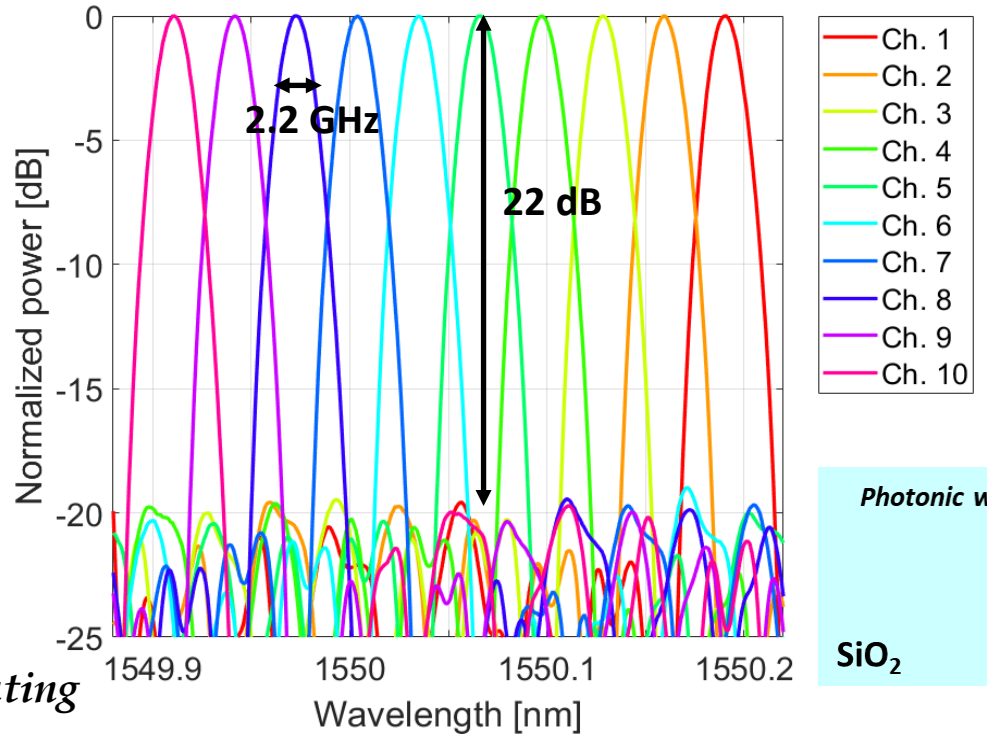
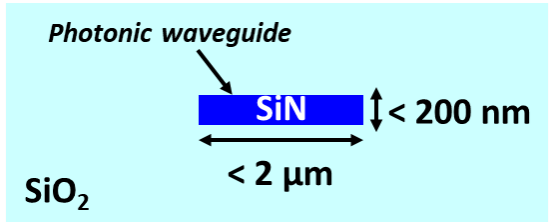
Photonic integrated channelizer

- **The core of HyMPI is an ultra-compact, narrow-bandwidth, and high-density photonic integrated channelizer (Serial Arrayed Waveguide Grating - SAWG) with 10 output ports**



- **The SAWG divides the upconverted microwave spectrum (in the optical domain) in 10 narrowband outputs**





US Patent 11852864 – Title: Serial Arrayed Waveguide Grating

Gambini, et al., 2024, doi: 10.1109/JLT.2024.3349932

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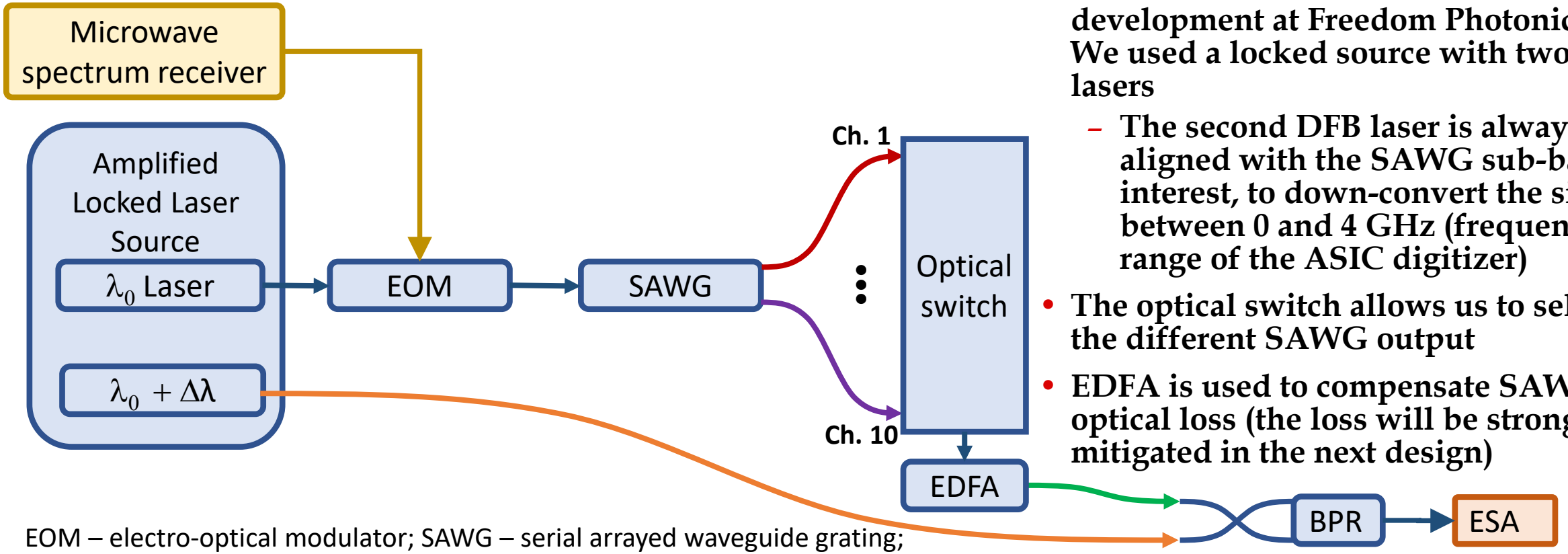
Experimental setup

- **The performance of the HyMPI photonic link has been evaluated with the following experimental setup:**



- **The Multi-tone laser source is under development at Freedom Photonics. We used a locked source with two DFB lasers**
  - **The second DFB laser is always aligned with the SAWG sub-band of interest, to down-convert the signals between 0 and 4 GHz (frequency range of the ASIC digitizer)**
- **The optical switch allows us to select the different SAWG output**
- **EDFA is used to compensate SAWG loss optical loss (the loss will be strongly mitigated in the next design)**

EOM – electro-optical modulator; SAWG – serial arrayed waveguide grating;
EDFA – erbium doped fiber amplifier; ESA – electrical spectrum analyzer;

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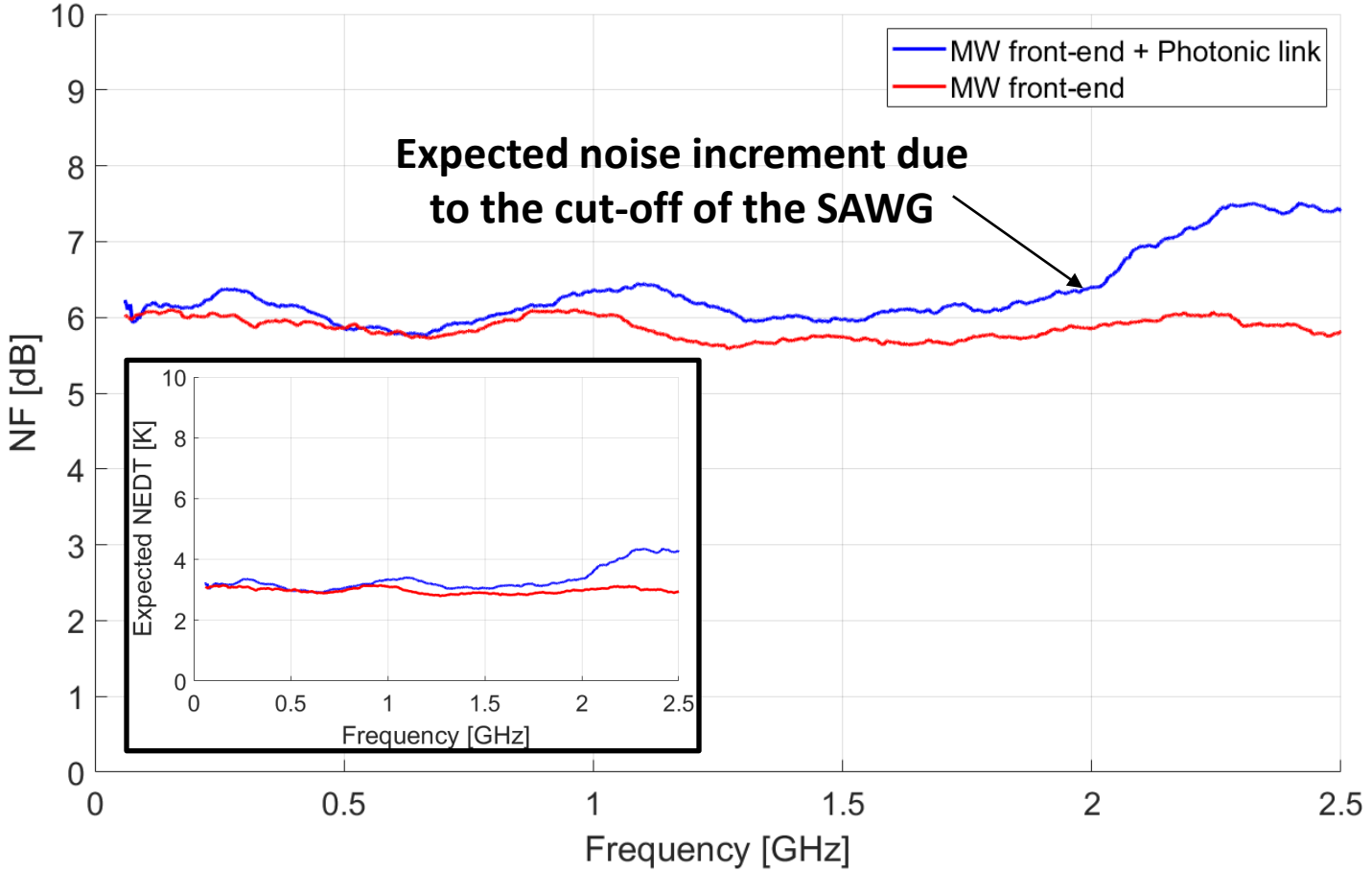
Experimental results

Base-band down-converted channel noise analysis:



- The noise figure (NF) measurements and prediction of the noise equivalent differential temperature (NEDT) were performed at:
  - Resolution: 8 MHz
  - Integration time: 18 ms
- Measured NF and expected NEDT of the MW front end are: 6 dB and 3 K, respectively
- The results show that HyMPI enables <u>hyperspectral resolution sounding without increasing the noise</u>

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Conclusions

- **HyMPI enables wide-band, hyperspectral resolution and contiguous spectral coverage without increasing the noise level:**
  - **We demonstrated the capabilities at hyperspectral resolution (8 MHz)**
  - **We demonstrated that the photonic link does not increase the noise**

- **PICs can overcome the limitation of the current MW technology:**
  - **As predicted by our models, PICs do not contribute to the noise of the system**
  - **They can minimize the size, weight, power consumption and costs of the instrument**

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Conclusions

- **HyMPI's photonic link is suitable for Earth science, being "limited" by the MW RF technology at this point.**
- **Going from 22, sparsely sampled channels on ATMS to thousands channels will enable improved retrievals of surface and atmospheric temperature and water vapor.**
- **Simulated results have shown a 50% improvement in atmospheric temperature and water vapor retrievals, including in the Earth's Planetary Boundary Layer (Gambacorta et al., 2023, doi: 10.1109/JSTARS.2023.3269697)**
- **HyMPI promises to unveil new horizons in atmospheric science and improved predictive knowledge of climate change, along with enhanced data users applications of importance for societal benefit, such as improved numerical weather prediction and early warning of extreme events.**

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Thank you for your support

Internal Research and Development (IRAD)

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Questions?

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Backup slides

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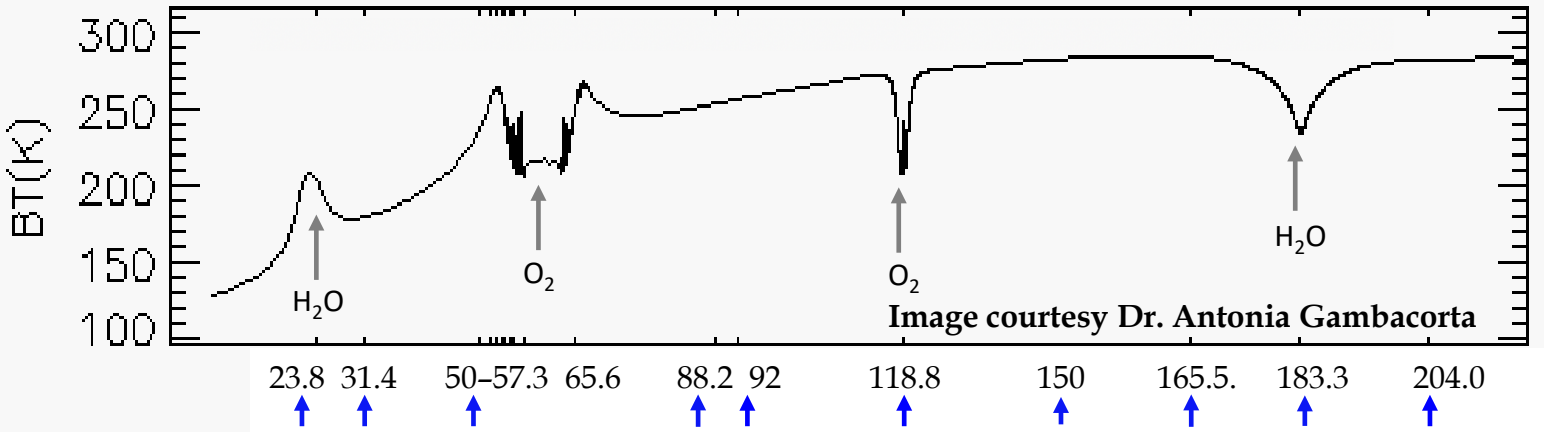
Why Hyperspectral Microwave for Earth's Atmospheric Sounding?

Earth's surface emitted Blackbody Radiation, transmitted through the atmosphere and measured from a space-borne microwave sensor



- **MW sensors from the current and planned programs have a very limited, sparsely sampled set of channels, leaving a significant part of the spectrum entirely unexploited**

- **Measured microwave (MW) radiation in the thermal region (10 – 250 GHz) is inverted to retrieve information on atmospheric temperature, water vapor and clouds**

➔ **These products are used in numerous applications of societal benefit such as numerical weather prediction models, nowcasting of extreme events, climate science.**

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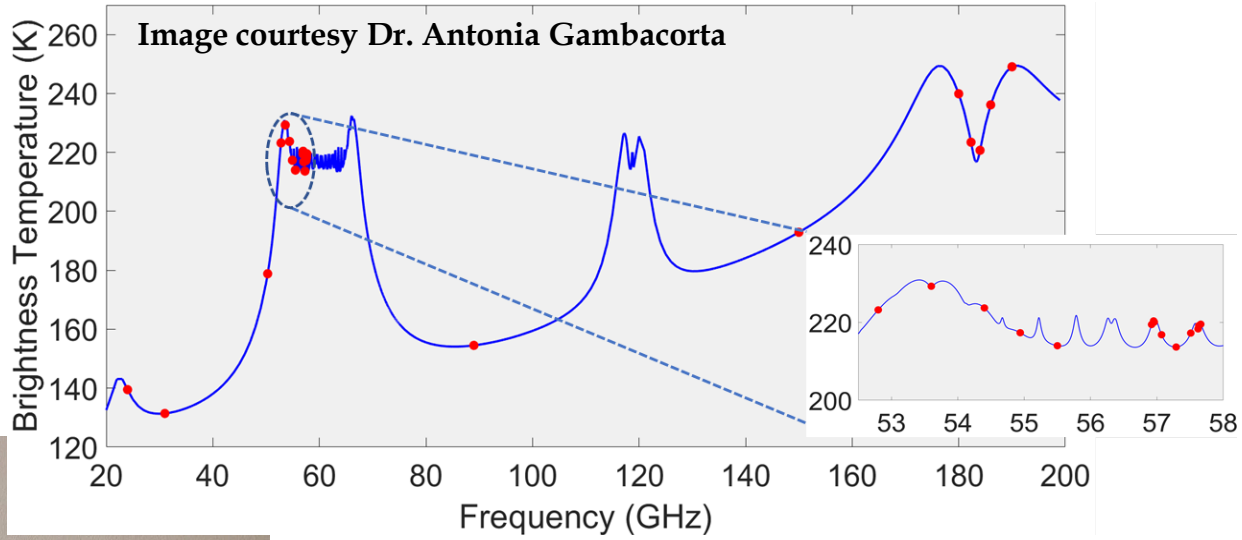
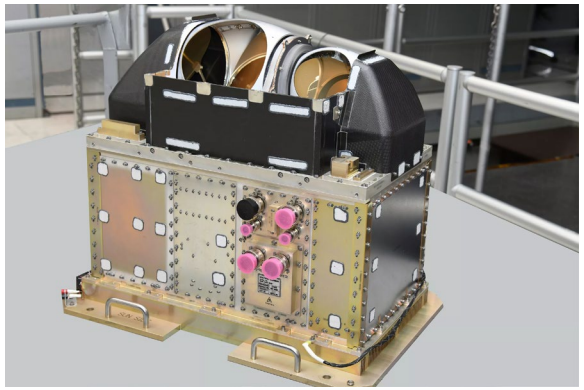
Technology: state of the art

Radio-frequency systems do not meet science requirements.

- Large number of components
- High power consumption
- Larger size & weight
- Limited bandwidth for components

Dozen sparsely sampled channels:

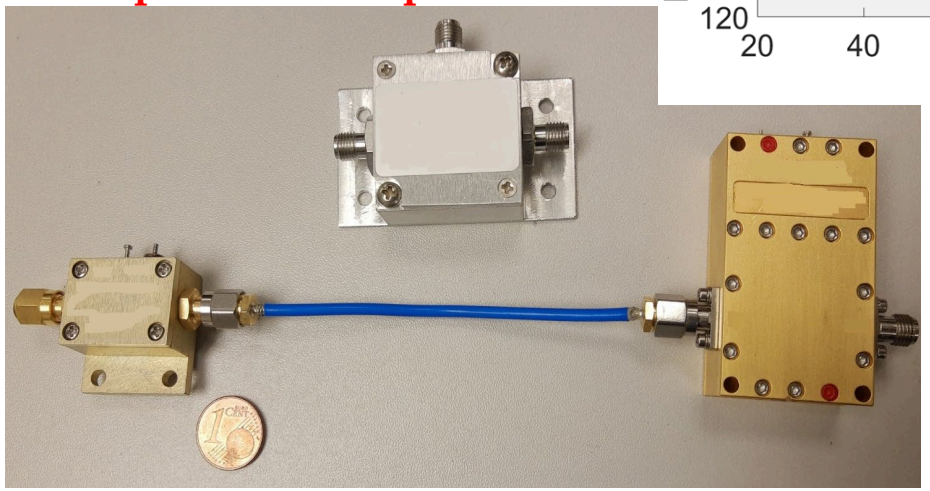




www.nesdis.noaa.gov

Advanced technology Microwave Sounder (ATMS)

Example of RF components:



The technology limitation

- Low resolution
- Large information loss
- Hard to tune
- Low level of redundancy

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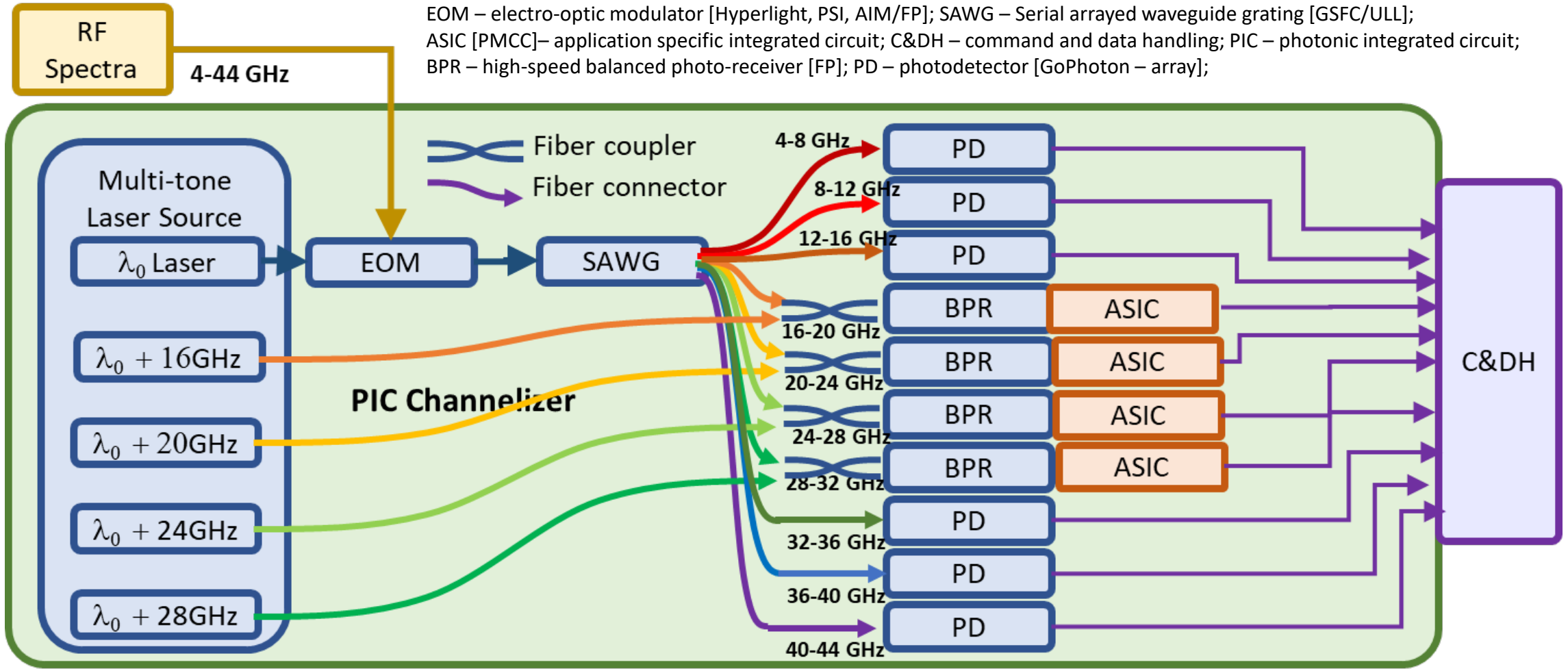
The HyMPI diagram

RF – radio frequency; LNA – low-noise amplifier; Multi-tone Laser source [Freedom Photonics (FP)];
EOM – electro-optic modulator [Hyperlight, PSI, AIM/FP]; SAWG – Serial arrayed waveguide grating [GSFC/ULL];
ASIC [PMCC]– application specific integrated circuit; C&DH – command and data handling; PIC – photonic integrated circuit;
BPR – high-speed balanced photo-receiver [FP]; PD – photodetector [GoPhoton – array];



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